

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
4 November 2004 (04.11.2004)

PCT

(10) International Publication Number
WO 2004/095135 A2

(51) International Patent Classification⁷: **G03F**
(21) International Application Number:
PCT/US2004/011287
(22) International Filing Date: 12 April 2004 (12.04.2004)
(25) Filing Language: English
(26) Publication Language: English
(30) Priority Data:
60/464,392 17 April 2003 (17.04.2003) US

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

(71) Applicant (for all designated States except US): **NIKON CORPORATION** [JP/JP]; 2-3 Marunouchi, 3-Chome, Chiyoda-ku, Tokyo, 100-8331 (JP).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **NOVAK, W., Thomas** [US/US]; 1205 Lakeview Drive, Hillsborough, CA 94010 (US).

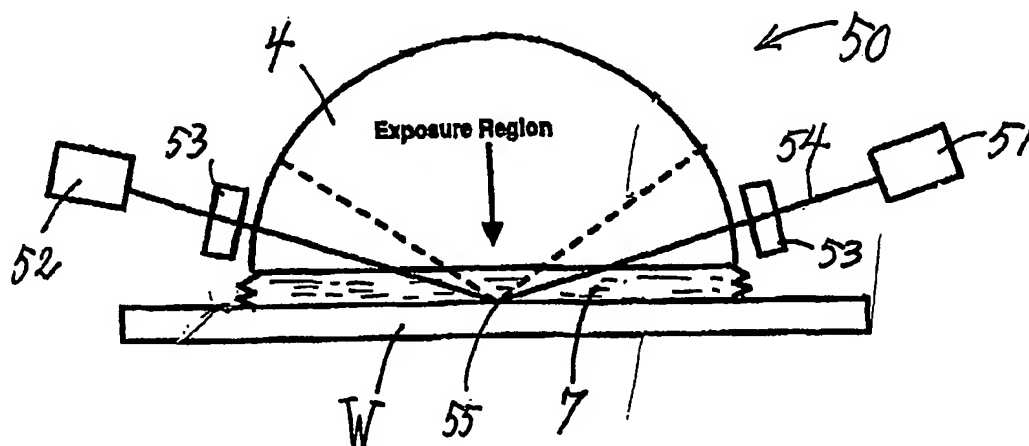
Published:

— without international search report and to be republished upon receipt of that report

(74) Agent: **NISHIMURA, Kelch**; Beyer Weaver & Thomas, LLP, P.O. Box 778, Berkeley, CA 94704-0778 (US).

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: **OPTICAL ARRANGEMENT OF AUTOFOCUS ELEMENTS FOR USE WITH IMMERSION LITHOGRAPHY**



(57) Abstract: An autofocus unit is provided to an immersion lithography apparatus for having a fluid over a target surface of a workpiece and an image pattern projected on this target surface through the fluid. The autofocus unit has an optical element such as a projection lens disposed opposite and above the target surface. An autofocus light source is arranged to project a light beam obliquely at a specified angle such that this light beam passes through the fluid and is reflected by the target surface of the workpiece at a specified reflection position which is below the optical element. A receiver receives and analyzes the reflected light. Correction lenses may be disposed on the optical path of the light beam for correcting propagation of the light beam.

OPTICAL ARRANGEMENT OF AUTOFOCUS ELEMENTS FOR USE WITH IMMERSION LITHOGRAPHY

BACKGROUND OF THE INVENTION

This invention relates to an optical arrangement of autofocus elements for use with immersion lithography.

In semiconductor lithography systems in use today, automatic focusing and leveling (AF/AL) is typically accomplished by passing a low angle of incidence optical beam onto the surface of a silicon wafer and detecting its properties after subsequent reflection from the wafer surface. The wafer height is determined by optical and electrical processing of the reflected light beam. This beam passes under the last element of the projection lens. The source and receiver optics are typically mounted to a stable part of the system, close to the projection optics mounting position.

In immersion lithography, a liquid such as water fills the space between the last surface of the projection lens and the wafer. At the edge of the water, typically at the edge of the lens or supported structure near the edge of the lens, the liquid-air boundary is not well defined and changing rapidly. It is not possible to transmit an AF/AL beam through this interface without substantial disruption and subsequent loss of signal, and hence performance.

It is therefore a general object of this invention to provide a way to introduce AF/AL beams into the liquid layer without such disruption so as to preserve the optical accuracy and stability required.

More specifically, it is an object of this invention to provide an apparatus and a method for allowing AF/AL light beams to be used as in conventional lithography without the disrupting influence of the liquid immersion boundary at the edge of the lens.

SUMMARY OF THE INVENTION

Autofocus units according to this invention are for an immersion lithography apparatus which may be described generally as comprising not only a reticle stage arranged to retain a reticle, a working stage arranged to retain a workpiece with a

target surface and an optical system including an illumination source and an optical element such as a lens positioned opposite and above the workpiece for having an image pattern of the reticle projected on the workpiece by radiation from said illumination source, but also a fluid-supplying device for providing a fluid into the space defined between the optical element and the workpiece such that the fluid contacts both the optical element and the target surface of the workpiece. The optical element positioned opposite to the workpiece may be treated as a component of the autofocus unit itself which may be characterized as further comprising an autofocus light source serving to project a light beam obliquely at a specified angle such that this light beam passes through the fluid and is reflected by the target surface of the workpiece at a specified reflection position which is below the optical element, and a receiver for receiving and analyzing the light beam reflected by the target surface. Correction lenses may preferably be disposed on the optical path of the light beam projected from the autofocus light source for correcting propagation of the light beam.

As an alternative embodiment, the optical element opposite the workpiece may be cut on its two mutually opposite sides and optically transparent wedge-shaped elements may be placed under these cuts such that the light beam from the autofocus light source will pass through them as it is passed through the fluid to be reflected on the target surface of the workpiece and to reach the receiver without passing through the optical element at all. In order to cope with the potential problem of bubbles that may be formed due to the gap between the wedge element and the optical element, the gap may be filled with a suitable material, made sufficiently narrow such as less than 2.0mm such that capillary forces will keep the gap filled with the fluid, or provided with means for supplying a small suction to cause the fluid to move up through the gap or to supply the fluid such that that the gap can be kept filled. The boundary surface through which the light beam from the autofocus light source is refracted into the fluid from the interior of the wedge element need not be parallel to the target surface of the workpiece but may be appropriately sloped, depending on the indices of refraction of the materials that affect the design of the unit.

BRIEF DESCRIPTION OF THE DRAWING

The invention, together with further objects and advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a schematic cross-sectional view of an immersion lithography apparatus that incorporates the present invention;

Fig. 2 is a process flow diagram illustrating an exemplary process by which semiconductor devices are fabricated using the apparatus shown in Fig. 1 according to the present invention;

Fig. 3 is a flowchart of the wafer processing step shown in Fig. 2 in the case of fabricating semiconductor devices according to the present invention;

Fig. 4 is a schematic side cross-sectional view of an autofocus unit embodying this invention;

Fig. 5 is a schematic side cross-sectional view of another autofocus unit embodying this invention;

Fig. 6 is an enlarged view of a circled portion VI of Fig. 5.

Figs. 7, 8 and 9 are schematic side cross-sectional views of portions of other autofocus unit embodying this invention according to different embodiment of the invention.

Throughout herein, items and components that are equivalent or similar are sometimes indicated by the same numeral in different figures and may not necessarily be explained in a repetitious manner.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

Fig. 1 shows the general structure of an immersion lithography apparatus 100 which may incorporate the optical arrangement of autofocus elements embodying this invention.

As shown in Fig. 1, the immersion lithography apparatus 100 comprises an illuminator optical unit 1 including a light source such as a KrF excimer laser unit, an optical integrator (or homogenizer) and a lens and serving to emit pulsed ultraviolet light IL with wavelength 248nm to be made incidence to a pattern on a reticle R. The pattern on the reticle R is projected on a wafer W coated with a photoresist at a specified magnification (such as 1/4 or 1/5) through a telecentric light projection unit PL. The pulsed light IL may alternatively be ArF excimer laser light with wavelength 193nm, F₂ laser light with wavelength 157nm or the i-line of a mercury lamp with

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175
2176
2177
2178
2179
2180
2181
2182
2183
2184
2185
2186
2187
2188
2189
2190
2191
2192
2193
2194
2195
2196
2197
2198
2199
2200
2201
2202
2203
2204
2205
2206
2207
2208
2209
2210
2211
2212
2213
2214
2215
2216
2217
2218
2219
2220
2221
2222
2223
2224
2225
2226
2227
2228
2229
2230

surface of the wafer W and the lower surface of the last-stage optical element 4 of the light projection unit PL at least while the pattern image of the reticle R is being copied on the wafer W.

The last-stage optical element 4 of the light projection unit PL is affixed to the cylindrical housing 3. In an optional embodiment, the last-stage optical element 4 may be made removable for cleaning or maintenance.

The liquid 7 is supplied from a liquid supply unit 5 that may comprise a tank, a pressure pump and a temperature regulator (not individually shown) to the space above the wafer W under a temperature-regulated condition and is collected by a liquid recovery unit 6. The temperature of the liquid 7 is regulated to be approximately the same as the temperature inside the chamber in which the lithography apparatus 100 itself is disposed. Numeral 21 indicates source nozzles through which the liquid 7 is supplied from the supply unit 5. Numeral 23 indicates recovery nozzles through which the liquid 7 is collected into the recovery unit 6. It is to be reminded, however, that the structure described above with reference to Fig. 1 is not intended to limit the scope of the immersion lithography apparatus to which the liquid-removing methods and devices of the present invention are applicable. In other words, autofocus units of the present invention may be incorporated into immersion lithography apparatus of many different kinds. In particular, it is to be reminded that the numbers and arrangements of the source and recovery nozzles 21 and 23 around the light projection unit PL may be designed in a variety of ways for establishing a smooth flow and quick recovery of the immersion liquid 7.

Fig. 4 shows an autofocus unit 50 (not shown in Fig. 1) according to this invention which may be incorporated into an immersion lithography system such as shown at 100 in Fig. 1 but the invention is not intended to be limited by the specific type of the system into which it is incorporated. In this example, the last-stage optical element 4 of the light projection unit PL is a hemispherically shaped projection lens with its planar surface facing downward opposite to the upper surface (the "target surface") of the wafer W a space left in between. An autofocus light source 51 is arranged such that its AF/AL light beam 54, emitted obliquely with respect to the target surface of the wafer W, passes through a lower peripheral part of this lens 4 and then is refracted into the immersion liquid 7 so as to be reflected by the target surface of the wafer W at a specified reflection position 55. A receiver 52 for receiving and

analyzing the reflected AF/AL light beam 54 is appropriately positioned on the opposite side of the light projection unit PL. Numerals 53 each indicate a what may be referred to as a correction lens disposed on the path of the AF/AL light beam 54 for correcting light propagation. Since the interface between the lens 4 and the liquid 7 is well defined and essentially free of bubbles, the light beams are unimpeded and can provide good signals to maintain high accuracy. In Fig. 4, broken lines indicate the exposure light cone, or the boundary of the exposure region.

Fig. 5 shows another autofocus unit 60 according to another embodiment of the invention. Its components that are similar to those described above with reference to Fig. 5 are indicated by the same numerals. The unit 60 shown in Fig. 5 is characterized as having the lower surface of the last-stage optical element 4 of the light projection unit PL cut in two places facing respectively the autofocus light source 51 and the receiver 52. The cut surfaces may be preferably flat, as shown in Fig. 5, and the last-stage optical element 4 is still functionally and essentially a hemispherical lens. Optically transparent parts, referred to as wedge elements 61 and 62, are placed on both sides of the lens 4 under these cut surfaces, the element 61 being on the side of the autofocus light source 51 and the element 62 being on the side of the receiver 52. The cuts and the wedge elements 61 and 62 are so designed that the AF/AL light beam 54 from the autofocus light source 51 will pass through the wedge element 61 and refracted into the immersion liquid 7 without passing through the lens 4 and, after being reflected by the target surface of the wafer W at the reflection position 55, will be refracted into the wedge element 62 and received by the receiver 52 again without passing through the lens 4. This embodiment is advantageous because the wedge elements can be made of a different material from the lens element 4 such as optical glass.

The lower interface between the wedge elements 61 and 62 and the lens 4 is important from the points of view of correct optical performance and generation of bubbles in the immersion liquid 7. With reference to Fig. 6, which shows more in detail the portion of the wedge element 61 in a close proximity of the lens 4, the gap D therebetween is a potential source of air bubbles, which may be entrained under the lens 4, adversely affecting its optical performance.

One of the solutions to this problem is to fill the gap with a suitable material or to press the wedge element 61 into contact with the lens 4 such that the gap D

becomes effectively zero and therefore does not perturb the liquid interface. Another solution is to keep D approximately equal to or less than 2.0mm such that capillary forces cause the liquid 7 to fill the gap and keep it filled even while the wafer W is moved under the lens 4. A third solution is to supply a small suction to cause the liquid 7 to move up inside the gap D and to prevent air from moving downward, as shown in Fig. 7 wherein numeral 70 indicates an air pump for providing the suction. Fig. 8 shows still another solution whereby a source 72 of the liquid 7 is supplied above the opening of the gap D to keep the gap D filled with the liquid 7.

The invention has been described above with reference to only a limited number of arrangements but they are not intended to limit the scope of the invention. Many modifications and variations are possible within the scope of the invention. The shaped of the wedge elements 61 and 62, for example need not be as described above with reference to Fig. 6. Depending, for example, upon the desired angle of incidence of the AF/AL light beam 54 relative to the indices of refraction of the immersion liquid 7 and the material of the wedge element 61, it may be advantageous, as shown in Fig. 9, to provide the wedge element 61 with a sloped surface portion 64 such that the AF/AL light beam 54 passing through the wedge element 61 will be refracted into the immersion liquid 7 not necessarily through a horizontal boundary surface as shown in Fig. 6 but through this appropriately sloped surface portion 64. This will provide flexibility in the design of the arrangement embodying this invention.

Fig. 2 is referenced next to describe a process for fabricating a semiconductor device by using an immersion lithography apparatus incorporating a liquid jet and recovery system embodying this invention. In step 301 the device's function and performance characteristics are designed. Next, in step 302, a mask (reticle) having a pattern is designed according to the previous designing step, and in a parallel step 303, a wafer is made from a silicon material. The mask pattern designed in step 302 is exposed onto the wafer from step 303 in step 304 by a photolithography system such as the systems described above. In step 305 the semiconductor device is assembled (including the dicing process, bonding process and packaging process), then finally the device is inspected in step 306.

Fig. 3 illustrates a detailed flowchart example of the above-mentioned step 304 in the case of fabricating semiconductor devices. In step 311 (oxidation step), the wafer surface is oxidized. In step 312 (CVD step), an insulation film is formed on the

~~"wafer surface."~~ In step 313 (electrode formation step), electrodes are formed on the wafer by vapor deposition. In step 314 (ion implantation step), ions are implanted in the wafer. The aforementioned steps 311-314 form the preprocessing steps for wafers during wafer processing, and selection is made at each step according to processing requirements.

At each stage of wafer processing, when the above-mentioned preprocessing steps have been completed, the following post-processing steps are implemented.

During post-processing, initially, in step 315 (photoresist formation step), photoresist is applied to a wafer. Next, in step 316, (exposure step), the above-mentioned

exposure device is used to transfer the circuit pattern of a mask (reticle) to a wafer.

Then, in step 317 (developing step), the exposed wafer is developed, and in step 318 (etching step), parts other than residual photoresist (exposed material surface) are

removed by etching. In step 319 (photoresist removal step), unnecessary photoresist remaining after etching is removed. Multiple circuit patterns are formed by repetition

of these preprocessing and post-processing steps.

While a lithography system of this invention has been described in terms of several preferred embodiments, there are alterations, permutations, and various substitute equivalents which fall within the scope of this invention. It should also be noted that there are many alternative ways of implementing the methods and apparatuses of the present invention. It is therefore intended that the following appended claims be interpreted as including all such alterations, permutations, and various substitute equivalents as fall within the true spirit and scope of the present invention.

WHAT IS CLAIMED IS:

1. An apparatus comprising:
a workpiece having a first surface;
5 an optical element positioned adjacent the first surface of the workpiece and configured to project an image onto the first surface, there being a gap spaced between the first surface of the workpiece and the optical element, the gap being substantially filled with an immersion fluid; and
an autofocus system including:
10 an autofocus light source configured to emit a light beam through the immersion fluid onto the first surface of the workpiece; and
a receiver configured to receive the light beam reflected off the first surface of the workpiece.
- 15 2. The apparatus of claim 1 further comprising a transparent element, positioned between the autofocus light source and the immersion fluid, the transparent element being configured to cause the light beam to pass through the interface between the transparent element and the immersion fluid.
- 20 3. The apparatus of claim 2 wherein the transparent element is configured to control the refraction of the light beam at the interface between the transparent element and the immersion fluid.
4. The apparatus of claim 3 wherein the refraction of the light beam at the
25 interface ranges from 0 to 90 degrees.
5. The apparatus of claim 2 wherein the transparent element is made of a material selected from the group consisting of glass, plastic, calcium fluoride and fused silica.
30
6. The apparatus of claim 2 wherein the transparent element is the optical element.

The apparatus of claim 2 wherein the transparent element is positioned adjacent the optical element.

8. The apparatus of claim 2 wherein the transparent element is of a shape selected from the group consisting of rectangles, squares, ovals, wedges and spheres.

9. The apparatus of claim 7 wherein liquid is provided between the transparent element and the optical element.

10. The apparatus of claim 7 wherein a vacuum is provided in the space between the transparent element and the optical element.

11. The apparatus of claim 7 further comprising a suction-providing device for causing the immersion fluid to move up through the space between the transparent element and the optical element so that outside air is prevented from moving into the space.

12. The apparatus of claim 7 further comprising a fluid-supplying device configured to provide fluid in the space between the transparent element and the optical element.

13. A method in immersion lithography, said method comprising the steps of:

providing a workpiece having a first surface;
positioning an optical element adjacent the first surface of the workpiece, ;
projecting an image through the optical element onto the first surface, there being a gap spaced between the first surface of the workpiece and the optical element;
filling the gap substantially with an immersion fluid;
passing an autofocus light beam from an autofocus light source through the immersion fluid onto the first surface of the workpiece; and
receiving the light beam reflected off the first surface of the workpiece with a receiver.

The method of claim 13 further comprising the step of positioning a transparent element between the autofocus light source and the immersion fluid, the transparent element being configured to cause the light beam to pass through the interface between the transparent element and the immersion fluid.

5

15. The method of claim 14 wherein the transparent element is configured to control the refraction of the light beam at the interface between the transparent element and the immersion fluid.

10

16. The method of claim 15 wherein the refraction of the light beam at the interface ranges from 0 to 90 degrees.

15

17. The method of claim 14 wherein the transparent element is made of a material selected from the group consisting of glass, plastic, calcium fluoride and fused silica.

18. The method of claim 14 wherein the transparent element is the optical element.

20

19. The method of claim 14 wherein the transparent element is positioned adjacent the optical element.

20. The method of claim 14 wherein the transparent element is of a shape selected from the group consisting of rectangles, squares, ovals, wedges and spheres.

25

21. The method of claim 19 further comprising the step of providing liquid between the transparent element and the optical element.

30

22. The method of claim 19 further comprising the step of providing a vacuum in the space between the transparent element and the optical element.

23. The method of claim 19 further comprising the step of providing a suction-providing device for causing the immersion fluid to move up through the

space between the transparent element and the optical element so that outside air is prevented from moving into the space.

24. The method of claim 19 further comprising the step of providing a fluid-supplying device configured to provide fluid in the space between the transparent element and the optical element.

25. An immersion lithography apparatus comprising:
a reticle stage arranged to retain a reticle;
a working stage arranged to retain a workpiece with a first surface;
an optical system including an illumination source and an optical element, said optical element being positioned adjacent the first surface of the workpiece and configured to project an image onto the first surface, there being a gap spaced between the first surface of the workpiece and the optical element, the gap being substantially filled with an immersion fluid; and

an autofocus system including an autofocus light source configured to emit a light beam through the immersion fluid onto the first surface of the workpiece and a receiver configured to receive the light beam reflected off the first surface of the workpiece.

26. The apparatus of claim 25 further comprising a transparent element, positioned between the autofocus light source and the immersion fluid, the transparent element being configured to cause the light beam to pass through the interface between the transparent element and the immersion fluid.

27. The apparatus of claim 26 wherein the transparent element is configured to control the refraction of the light beam at the interface between the transparent element and the immersion fluid.

28. The apparatus of claim 27 wherein the refraction of the light beam at the interface ranges from 0 to 90 degrees.

29. The apparatus of claim 26 wherein the transparent element is made of a material selected from the group consisting of glass, plastic, calcium fluoride and fused silica.

5 30. The apparatus of claim 26 wherein the transparent element is the optical element.

 31. The apparatus of claim 26 wherein the transparent element is positioned adjacent the optical element.

10 32. The apparatus of claim 26 wherein the transparent element is of a shape selected from the group consisting of rectangles, squares, ovals, wedges and spheres.

 33. The apparatus of claim 31 wherein liquid is provided between the
15 transparent element and the optical element.

 34. The apparatus of claim 31 wherein a vacuum is provided in the space between the transparent element and the optical element.

20 35. The apparatus of claim 31 further comprising a suction-providing device for causing the immersion fluid to move up through the space between the transparent element and the optical element so that outside air is prevented from moving into the space.

25 36. The apparatus of claim 31 further comprising a fluid-supplying device configured to provide fluid in the space between the transparent element and the optical element.

 37. An object manufactured with the immersion lithography apparatus of
30 claim 25.

 38. A wafer on which an image has been formed by the immersion lithography apparatus of claim 25.

39. ~~A method for making an object using a lithography process, wherein~~
the lithography process utilizes the immersion lithography apparatus of claim 25.

40. A method for patterning a wafer using a lithography process, wherein
5 the lithography process utilizes the immersion lithography system of claim 25.

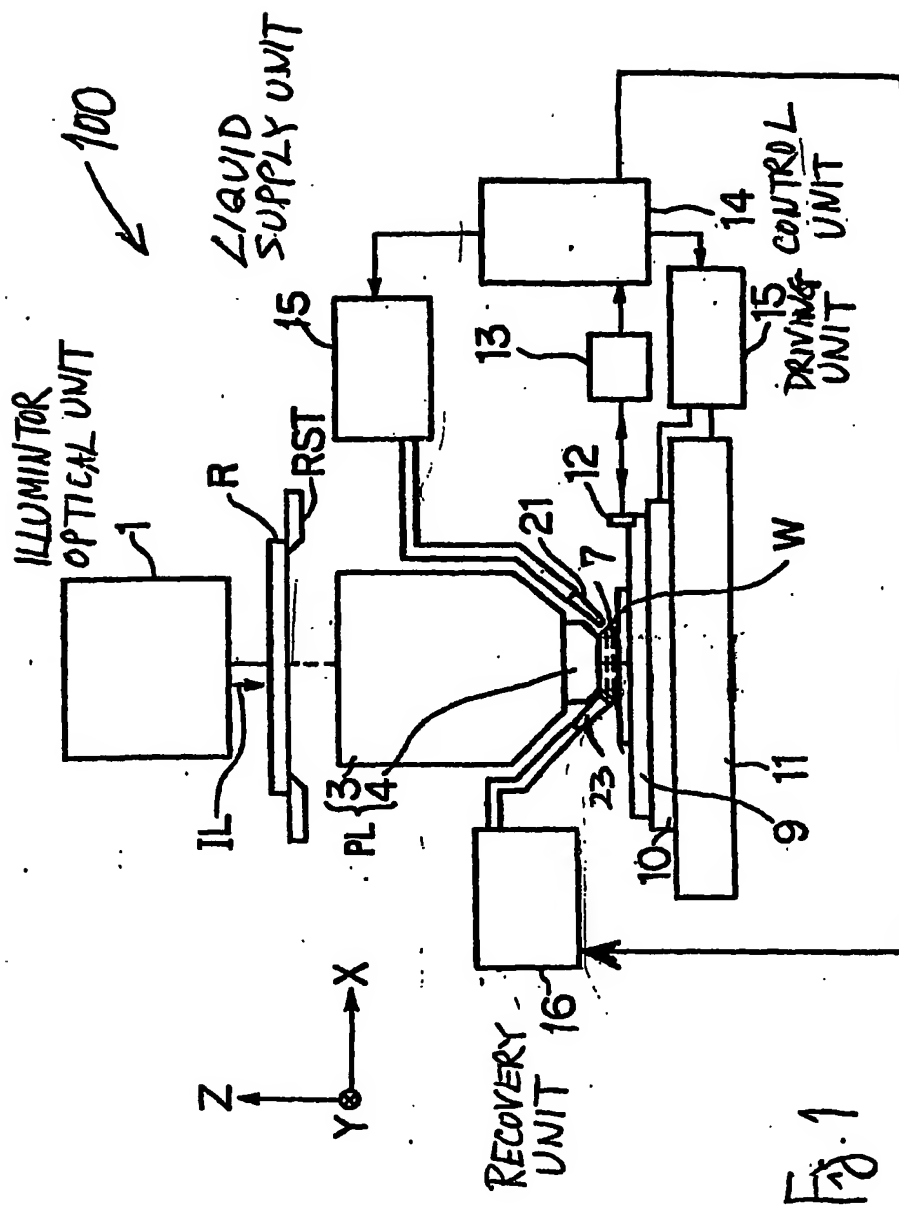


Fig. 1

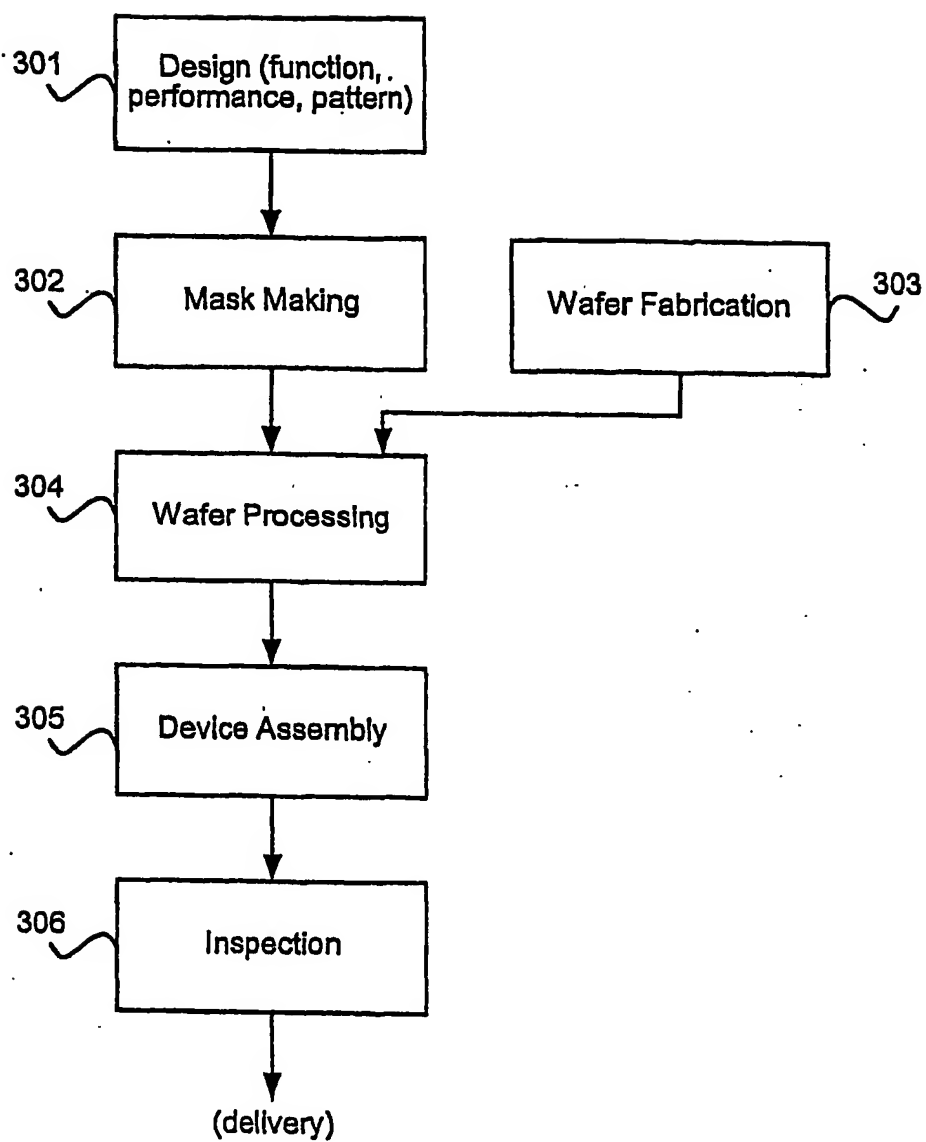


Fig. 2

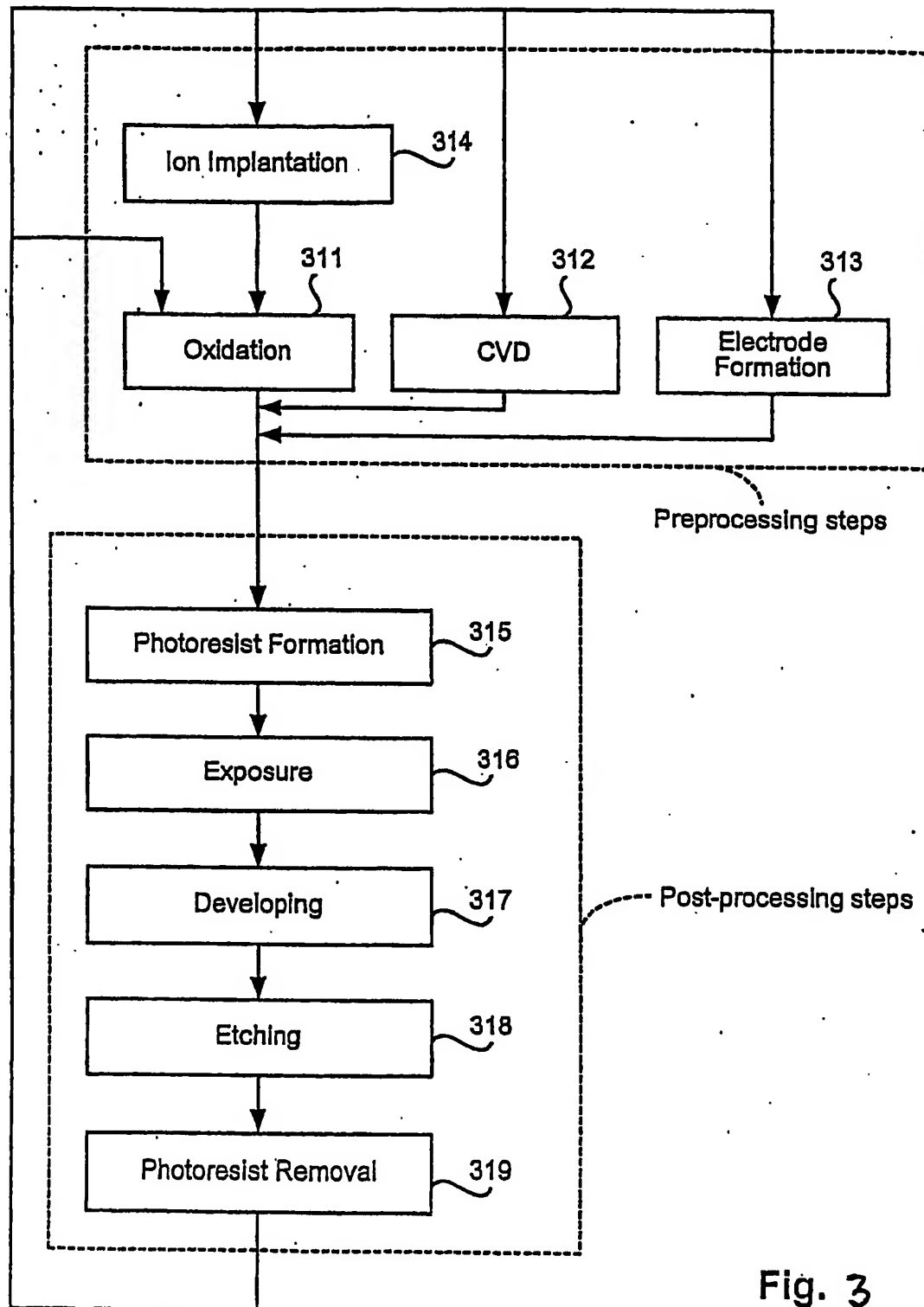
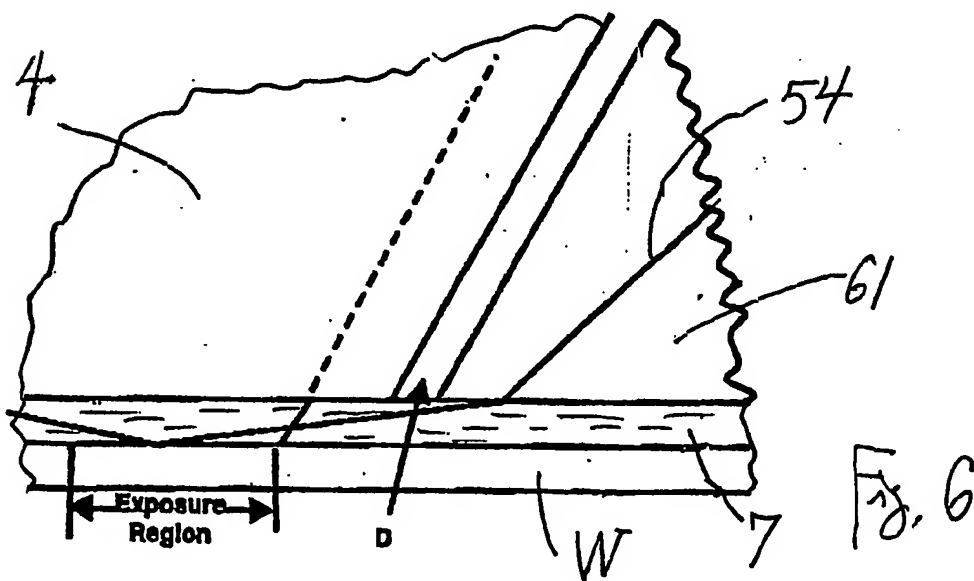
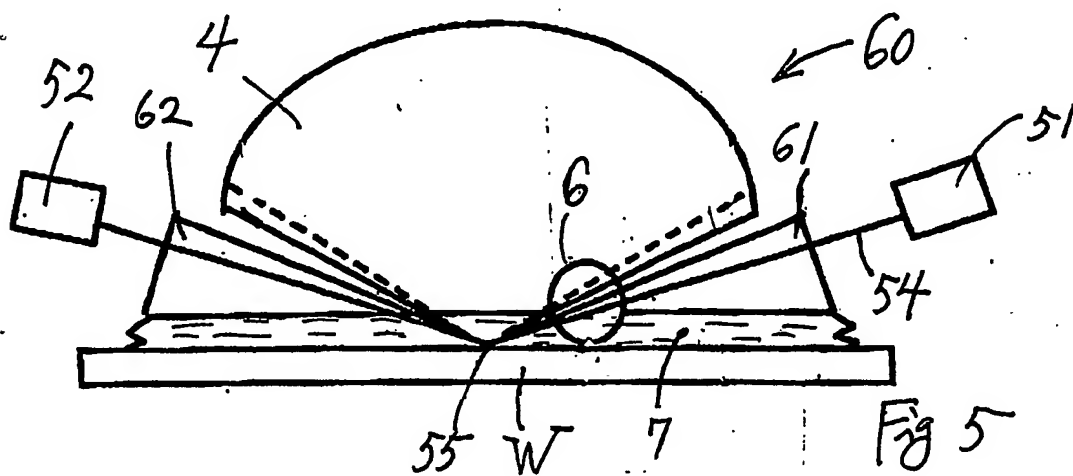
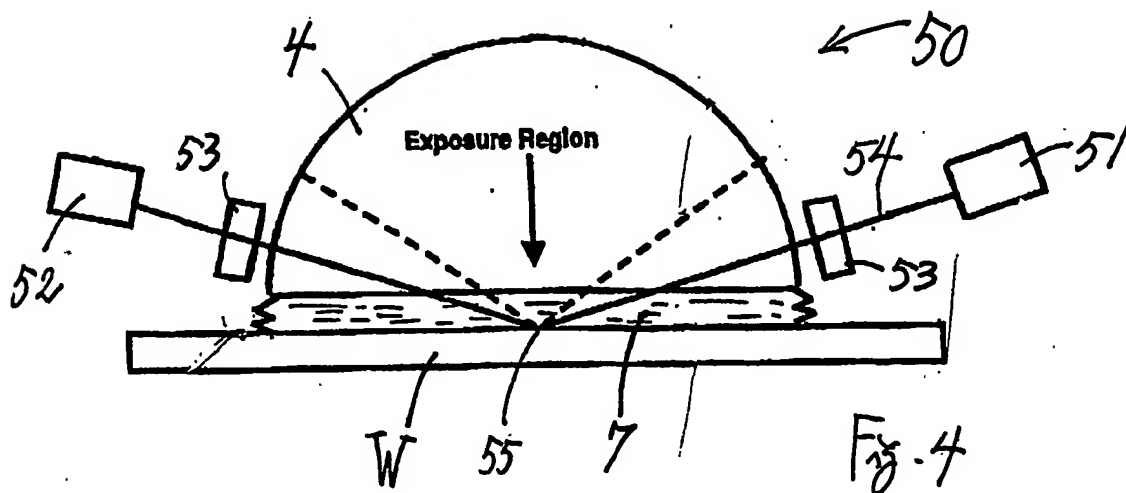
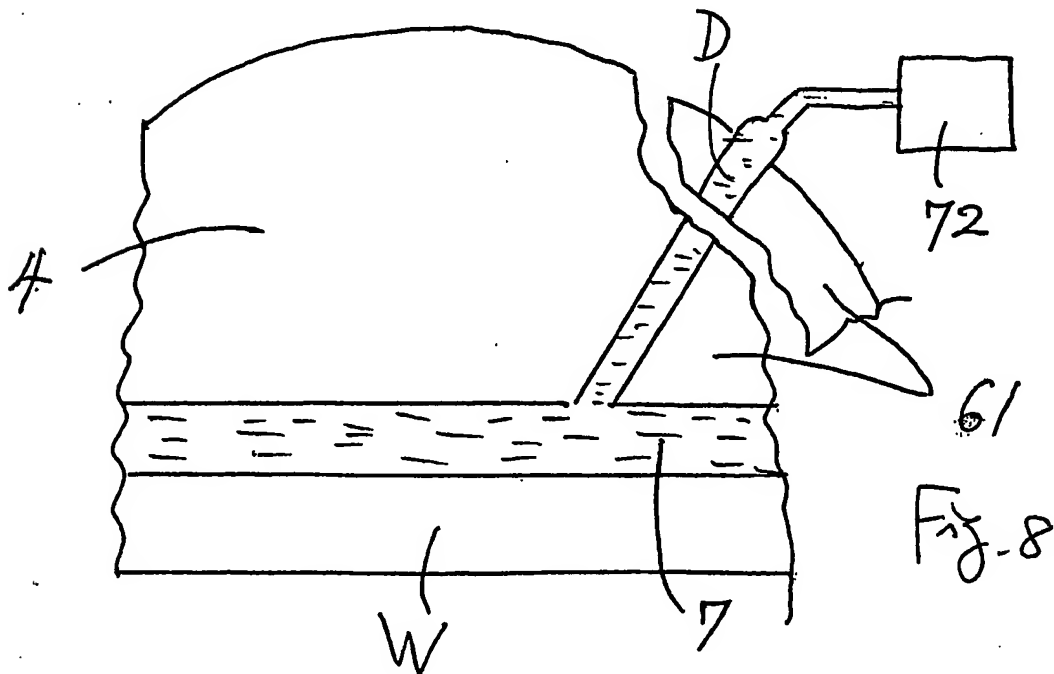
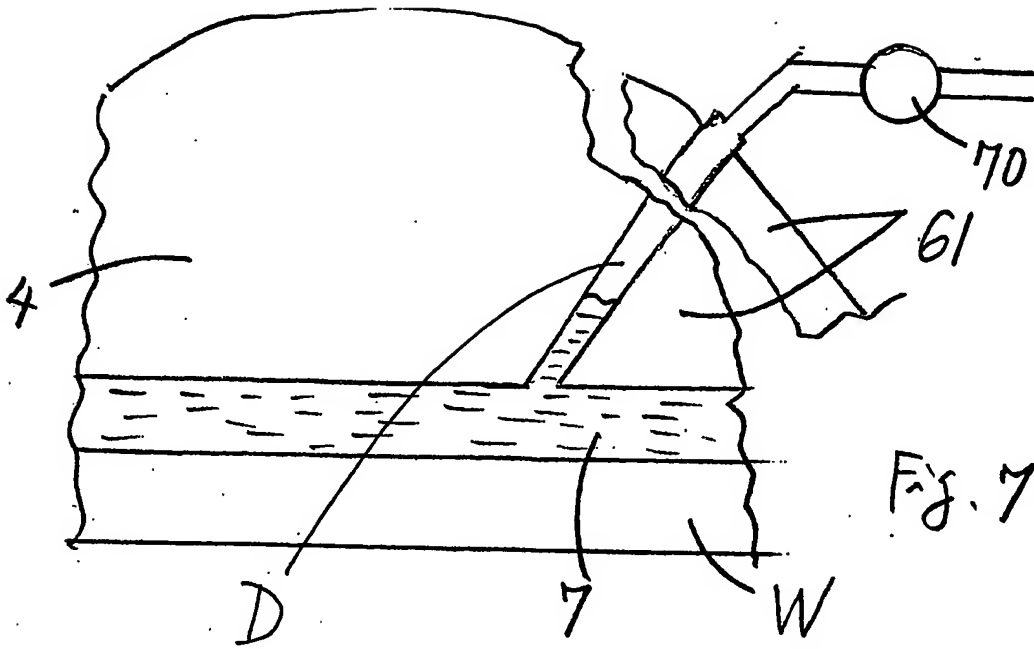
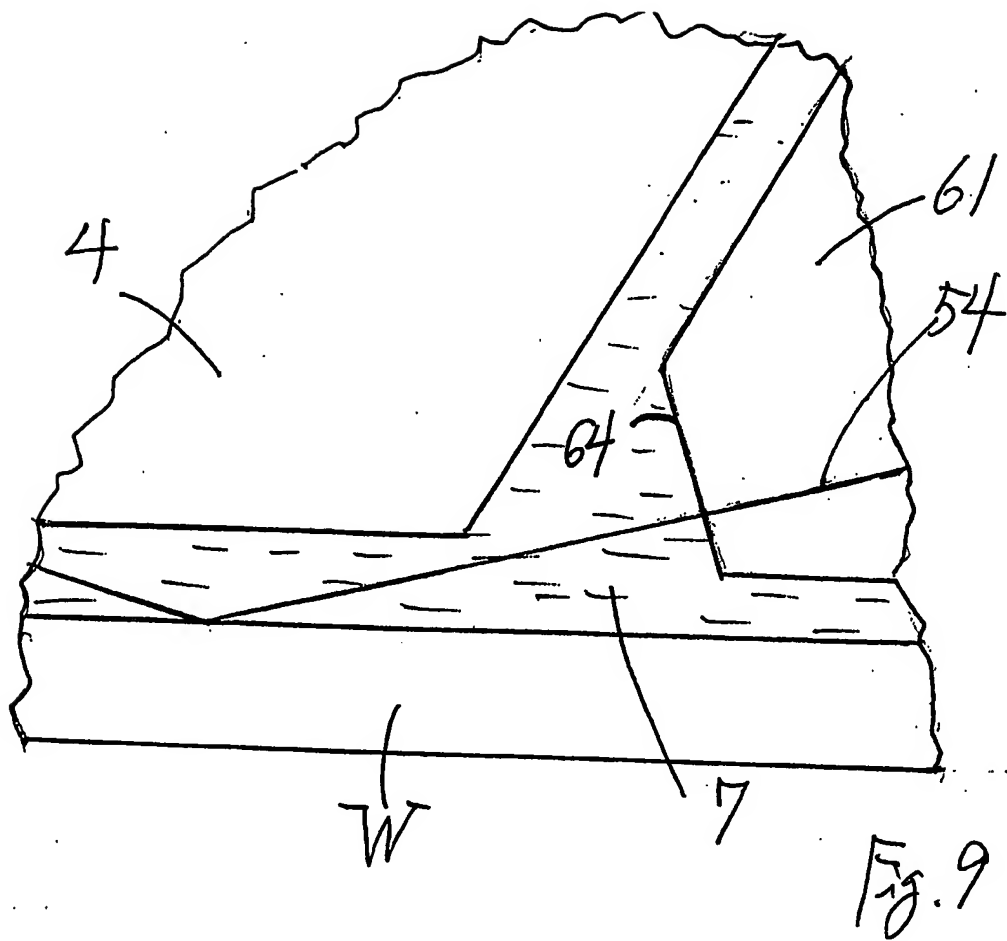


Fig. 3







(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
4 November 2004 (04.11.2004)

PCT

(10) International Publication Number
WO 2004/095135 A3

(51) International Patent Classification⁷: **G03B 27/34**

(21) International Application Number:
PCT/US2004/011287

(22) International Filing Date: 12 April 2004 (12.04.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/464,392 17 April 2003 (17.04.2003) US

(71) Applicant (for all designated States except US): **NIKON CORPORATION [JP/JP]**; 2-3 Marunouchi, 3-Chome, Chiyoda-ku, Tokyo, 100-8331 (JP).

(72) Inventor; and

(75) Inventor/Applicant (for US only): **NOVAK, W., Thomas** [US/US]; 1205 Lakeview Drive, Hillsborough, CA 94010 (US).

(74) Agent: **NISHIMURA, Kellchi**; Beyer Weaver & Thomas, LLP, P.O. Box 778, Berkeley, CA 94704-0778 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

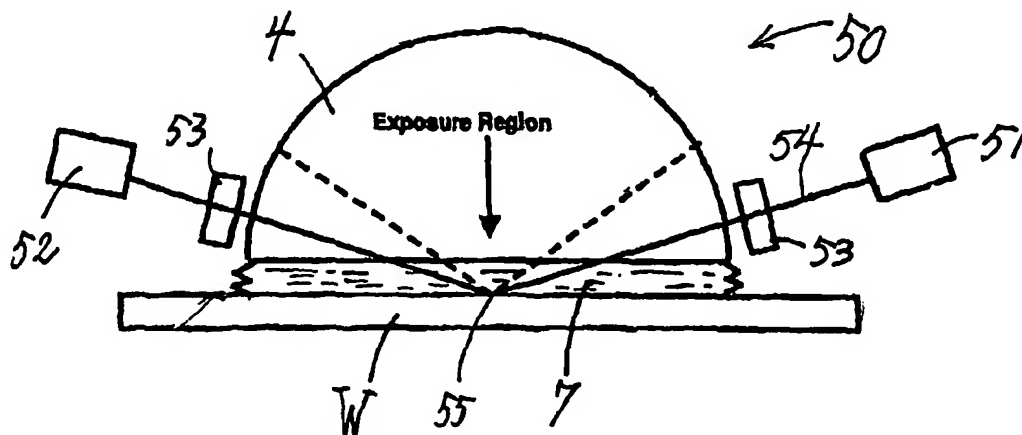
Published:

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

(88) Date of publication of the international search report:
9 December 2004

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: **OPTICAL ARRANGEMENT OF AUTOFOCUS ELEMENTS FOR USE WITH IMMERSION LITHOGRAPHY**



(57) Abstract: An autofocus unit is provided to an immersion lithography apparatus for having a fluid over a target surface of a workpiece and an image pattern projected on this target surface through the fluid. The autofocus unit has an optical element such as a projection lens disposed opposite and above the target surface. An autofocus light source is arranged to project a light beam obliquely at a specified angle such that this light beam passes through the fluid and is reflected by the target surface of the workpiece at a specified reflection position which is below the optical element. A receiver receives and analyzes the reflected light. Correction lenses may be disposed on the optical path of the light beam for correcting propagation of the light beam.

WO 2004/095135 A3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US04/11287

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G03B 27/34

US CL : 355/56

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 355/56; 250/201.2,201.3; 359/649

Documentation searched other than minimum documentation to the extent that such documents are included in the fields-searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2004/0000627 A1 (Schuster) 1 January 2004 (01.01.2004)	1-40
A	US 5365051 A (Suzuki et al.) 15 November 1994 (15.11.1994)	1-40
A	US 6633365 B2 (Suenaga) 14 October 2003 (14.10.2003)	1-40
A	US 5,677,525 A (Volcker et al.) 14 October 1997 (14.10.1997)	1-40
A,E	US 2004/0113043 A1 (Ishikawa et al.) 17 June 2004 (17.06.2004)	1-40
A-	US 3,721,827 (Reinheimer) 20 March 1973 (20.03.1973)	1-40

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T"

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X"

document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y"

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"

document member of the same patent family

Date of the actual completion of the international search

23 July 2004 (23.07.2004)

Date of mailing of the international search report

18 OCT 2004

Name and mailing address of the ISA/US

Mall Stop PCT, Attn: ISA/US
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Facsimile No. (703)305-3230

Authorized officer

Georgia Y. Epps

Telephone No. (703) 308-0956